# GEOLOGICAL SURVEY RESEARCH 1966

## Chapter C

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*Scientific notes and summaries of investigations by members of the Geologic, Topographic, and Water Resources Divisions in geology, hydrology, and related fields*

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## GEOLOGIC STUDIES

## GEOLOGICAL SURVEY RESEARCH 1966

This collection of 43 short papers is the second published chapter of "Geological Survey Research 1966." The papers report on scientific and economic results of current work by members of the Geologic, Topographic, and Water Resources Divisions of the U.S. Geological Survey.

Chapter A, to be published later in the year, will present a summary of significant results of work done during fiscal year 1966, together with lists of investigations in progress, reports published, cooperating agencies, and Geological Survey offices.

"Geological Survey Research 1966" is the seventh volume of the annual series Geological Survey Research. The six volumes already published are listed below, with their series designations.

Geological Survey Research 1960—Prof. Paper 400
Geological Survey Research 1961—Prof. Paper 424
Geological Survey Research 1962—Prof. Paper 450
Geological Survey Research 1963—Prof. Paper 475
Geological Survey Research 1964—Prof. Paper 501
Geological Survey Research 1965—Prof. Paper 525

# STRATIGRAPHY, PALEONTOLOGY, AND ISOTOPIC AGES OF UPPER MESOZOIC ROCKS IN THE SOUTHWESTERN WRANGELL MOUNTAINS, ALASKA

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Menlo Park, Calif.

*Abstract.*—Reconnaissance field observations, fossils, and potassium-argon ages have provided new information on the upper Mesozoic strata of the Wrangell Mountains. The Kotsina Conglomerate is probably Middle or lower Upper Jurassic. Sandstone along the Chetaslina River may be Callovian (Jurassic), and nearby unfossiliferous shale and sandstone is probably also upper Mesozoic. A unit of sandstone, siltstone, conglomerate, and calcarenite, previously thought to be gradational downward into the Kotsina Conglomerate, yielded Hauterivian and Barremian (Lower Cretaceous) fossils. Similar rocks occur in the northern Chugach Mountains and at Kuskulana Pass, where they rest on granodiorite dated as 141±5 m.y. Sandstone and siltstone with Albian (Lower Cretaceous) fossils rest on the Hauterivian to Barremian rocks at Kuskulana Pass, and shale and arkose of similar age rest on granodiorite dated as 126±4 m.y. near Mount Drum.

The southwestern Wrangell Mountains, and the adjacent lower Chitina Valley, occupy an important position between geologically better known areas—the upper Chitina Valley to the southeast, and the Nelchina area to the west (fig. 1). A reconnaissance survey of the upper Mesozoic rocks in the report area was made to determine regional stratigraphic relationships and the age of certain poorly dated formations. Knowledge of these relationships may have an economic application in the nearby Copper River lowland, where poorly exposed upper Mesozoic rocks are a possible source of petroleum.

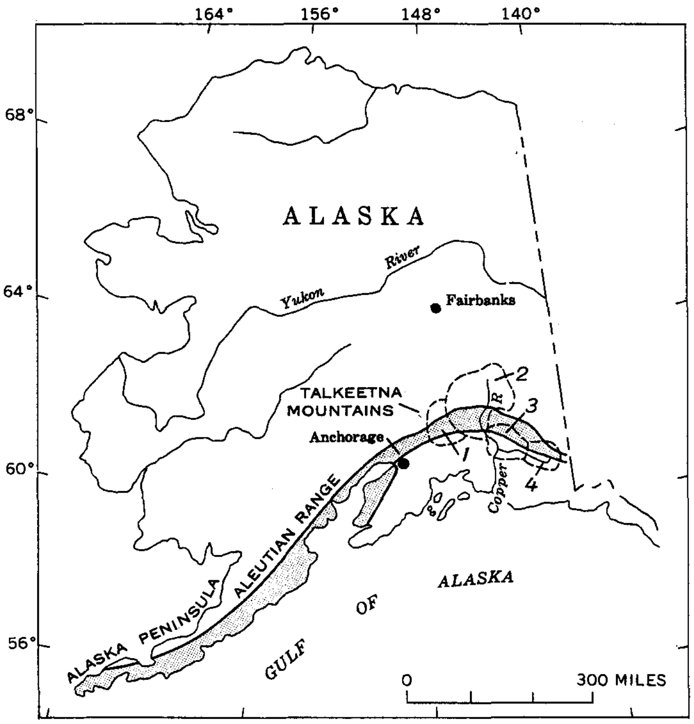


FIGURE 1.—Extent of upper Mesozoic rocks of the Matanuska geosyncline (shaded area) and area discussed in text. *1*, Nelchina area; *2*, Copper River lowland; *3*, southwestern Wrangell Mountains and lower Chitina Valley, (report area); and *4*, upper Chitina Valley.

The upper Mesozoic rocks rest unconformably upon altered upper Paleozoic sedimentary and volcanic rocks, Triassic basalt, and Upper Triassic limestone, black shale, and argillite. The pre-Jurassic rocks were strongly folded, intruded by plutonic rocks, and uplifted and deeply eroded by late Mesozoic time. They supplied most of the detritus found in the upper Mesozoic formations. The upper Mesozoic formations occupy a synclinal belt between the Chokosna River and Mount Drum and rest on Paleozoic rocks in a small area of the Chugach Mountain front near Chitina (fig. 2).

## PREVIOUS WORK

Pioneer reconnaissance surveys by Rohn (1900), Schrader and Spencer (1901), and Moffit and Maddren

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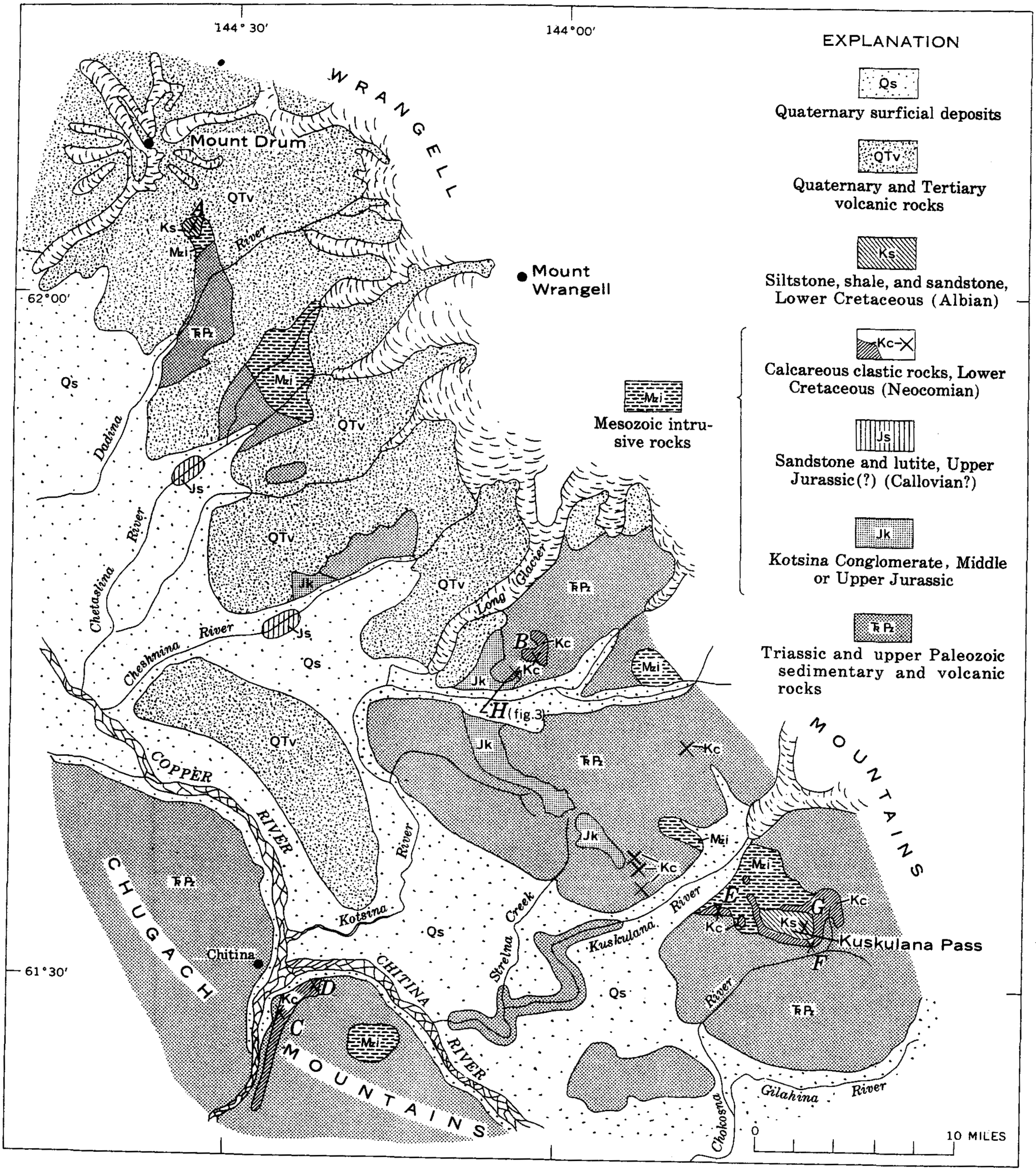


FIGURE 2.—Generalized geologic map of the southwestern Wrangell Mountains, Alaska, and generalized columnar sections of Cretaceous rocks in the area. Map after Moffit (1938). Large letters on map refer to stratigraphic sections on facing page.

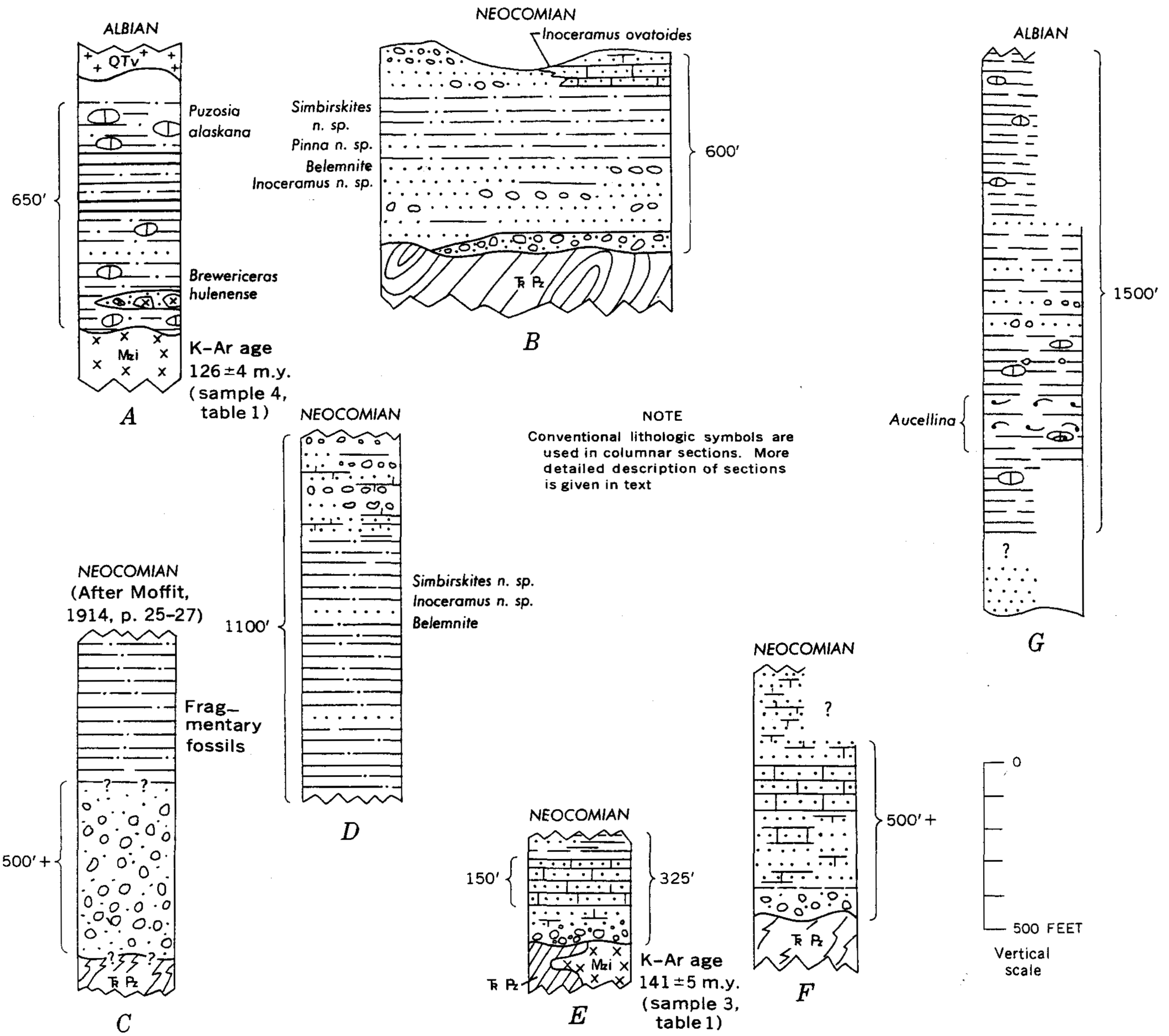


**Figure 2.—Continued**

(1909) resulted in the recognition of shale and limestone of supposed Late Jurassic or Early Cretaceous age in the Kotsina-Kuskulana Rivers area. These rocks were considered to be part of the Kennicott Formation, and of the thick Kotsina Conglomerate (Rohn, 1900, p. 431) of unknown age. In addition, Mendenhall (1905) mapped unaltered sedimentary rocks which he thought were Tertiary, in the Cheshnina, Chetaslina, and Dadina River drainage areas, but these rocks are now known to be upper Mesozoic. Near the mouth of the Chitina River, Moffit (1914) found two units of supposed Middle Jurassic age, a unit of "tuffaceous slate" overlying a "tuffaceous conglomerate".

In the Kotsina-Kuskulana Rivers district, Moffit and Mertie (1923) recognized three units of upper Mesozoic rocks to which they assigned a Late Jurassic age. The lowest unit is the Kotsina Conglomerate which unconformably overlies Upper Triassic shale and consists of massive conglomerate with rare shale lenses. The Kotsina was thought to be overlain by an unnamed unit of sandstone, conglomerate, and shale, and this in turn by an unnamed light-colored, highly fossiliferous limestone unit. Moffit and Mertie did not retain the name Kennicott Formation for the upper two units.

The sporadic distribution of these three units, and the fact that in no place were the upper two found in stratigraphic sequence with the Kotsina Conglomerate, led to uncertainty as to their relationships. The massive Kotsina Conglomerate was thought to grade laterally into soft yellowish-brown fossiliferous sandstone of the middle unit to the north. The lack of thick conglomerate in some places between the upper limestone unit and the Triassic formations, however, suggested that either the Kotsina was deposited in a restricted area, or that it was removed by erosion prior to deposition of the limestone.

Moffit (1938) published a summary of the geology of the entire Chitina Valley and adjacent area, but the relationships of the upper Mesozoic rocks of the Kotsina-Kuskulana Rivers area and nearby areas to those in other parts of the region were puzzling; they could not be correlated either lithologically or faunally with any other known sequence. Likewise, the supposed Middle Jurassic tuffaceous beds exposed near the mouth of the Chitina River could not be correlated with any others within the Chitina Valley region.

Imlay and Reeside (1954, p. 231) correlated the Kotsina Conglomerate with the basal part of the Matanuska Formation of supposed Coniacian (Late Cretaceous) age. The fossiliferous limestone was not mentioned and presumably was also regarded as part of the Matanuska Formation. They also assigned an Albian (Late Cretaceous) age to the Kennicott Formation, which crops out eastward from Kuskulana Pass, at the east margin of the present study area.

## PRESENT INVESTIGATIONS

This report is based on 9 days of helicopter-supported fieldwork carried out by Grantz in the summer of 1963, and contains the results of paleontologic studies by Jones and isotopic age measurements by Lanphere. An abstract of the data resulting from this collaborative work has been published previously (Grantz and others, 1965). Geologic observations were made throughout an area of about 1,200 square miles, but time did not permit tracing contacts or thorough examination of all exposures.

It is assumed that the potassium-argon ages discussed are at least minimum ages, because there is no evidence that biotite or hornblende from granitic rocks incorporate significant amounts of radiogenic argon at the time of crystallization. The plus-or-minus value assigned to each age (table 1) is the estimated standard deviation of analytical precision.

Where possible the formations discussed below will be correlated with the standard stages of northwestern Europe; a list of these stages for the Upper Jurassic and Cretaceous is presented in table 2.

## JURASSIC ROCKS

### Kotsina Conglomerate

The Kotsina Conglomerate, named by Rohn (1900, p. 431) for exposures on and near the Kotsina River, also crops out near the headwaters of Strelna Creek,

TABLE 1.—*Potassium-argon ages and analytical data*

[Potassium analyses by H. C. Whitehead; argon analyses by M. A. Lanphere]

| Sample No. | Sample description | Mineral | $K_2O$ analyses (percent) | Average $K_2O$ (percent) | $Ar_{rad}^{40}$ ($10^{-10}$ moles/g) | $\frac{Ar_{rad}^{40}}{Ar_{total}^{40}}$ | Apparent age (millions of years) | Field No. | Location |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Biotite granodiorite clast in Kotsina Conglomerate. | Biotite | 3.97, 3.97 | 3.97 | 9.633 | 0.90 | 157±6 | 63ALe 14b | Valdez (C–1) quadrangle; lat 61°44′00″ N., long 144°02′50″ W. (loc. *H*, fig. 2; fig. 3). |
| 2 | Porphyritic hornblende microdiorite dike cutting Kotsina Conglomerate. | Hornblende. | .668, .672 | .670 | 1.460 | .83 | 142±5 | 63AGz 213 | Valdez (C–1) quadrangle; lat 61°44′03″ N., long 144°03′02″ W. (loc. *H*, fig. 2; fig. 3). |
| 3 | Granodiorite near Kuskulana Pass. | do | .767, .784 | .776 | 1.684 | .87 | 141±5 | 63ALe 15 | McCarthy (C–8) quadrangle; lat 61°32′45″ N., long 143°42′30″ W. (loc. *E*, fig. 2). |
| 4 | Biotite granodiorite near Mount Drum. | Biotite | 7.29, 7.30 | 7.30 | 14.11 | .92 | 126±4 | 63AGz 162 | Gulkana (A–2) quadrangle; lat 62°03′09″ N., long 144°34′40″ W. (loc. *A*, fig. 2). |

Decay constants for $K^{40}$: $\lambda_\epsilon = 0.585 \times 10^{-10}$ year$^{-1}$; $\lambda_\beta = 4.72 \times 10^{-10}$ year$^{-1}$.
Atomic abundance of $K^{40} = 1.19 \times 10^{-4}$.

TABLE 2.—*Commonly used stage names of the Upper Jurassic and Cretaceous, including the stage names used in this report* [1]

| Series | Stage | |
|---|---|---|
| Upper Cretaceous | Maestrichtian | |
| | Campanian | |
| | Santonian | |
| | Coniacian | |
| | Turonian | |
| | Cenomanian | |
| Lower Cretaceous | Albian | |
| | Aptian | |
| | Neocomian | Barremian |
| | | Hauterivian |
| | | Valanginian |
| | | Berriasian |
| Upper Jurassic | Portlandian | |
| | Kimmeridgian | |
| | Oxfordian | |
| | Callovian | |

[1] Compiled from Imlay (1952, pl. 2) and Imlay and Reeside (1954, pl. 1).

and was found on the north side of the Cheshnina River valley during the present study (fig. 2).

The physiographic expression of the formation was aptly described by Moffit and Mertie (1923, p. 45) who noted that "The conglomerate mountains are rugged, with precipitous cliffs and a ragged skyline. Their dark color and rough surface give them a forbidding aspect, and in fact many of the ridges are practically impassable." The Kotsina is a very thick bedded, well-rounded, pebble-and-cobble conglomerate that contains boulders in some beds. Hand specimens are prevailingly dark or olive gray. The matrix is lithic or feldspathic sandstone which is poorly to fairly well sorted, or in some places dark, hard lutite. The formation contains interbeds and lenses of similar sandstone and of black lutite that commonly is carbonaceous and contains plant scraps. Some of the interbeds are tens of feet thick. The conglomerate clasts are principally dark rocks and of local origin, mostly altered volcanic rocks and Triassic limestone, argillite, and chert. Some light-colored and some mafic plutonic rocks, sandstone, and a little quartz are also present. The size of the clasts appears to decrease toward the southeast. The Kotsina Conglomerate rests unconformably upon rocks as young as latest Triassic. It is probably at least 2,000 to 2,500 feet thick, but its upper contact has not been recognized, and its full thickness is not known. Its estimated thickness and coarseness of grain size suggest that the Kotsina Conglomerate was deposited in a fault- or flexure-bounded basin, probably on or near shore.

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The only fossils found in the Kotsina Conglomerate are plant scraps in the lutite layers and Late Triassic mollusks in limestone clasts. Earlier workers based its age upon mollusks found in supposedly equivalent or gradationally overlying marine clastic rocks now known to be of late Neocomian Early Cretaceous (Hauterivian) age. These fossiliferous rocks are unrelated to the Kotsina Conglomerate, and in fact could not be found in contact with it. The supposedly equivalent rocks have been variously considered to be Late Jurassic, Jurassic or Cretaceous, Early Cretaceous, or Late Cretaceous, and the age of the Kotsina Conglomerate varied with the age assigned to these beds.

The Kotsina Conglomerate is intruded by porphyritic hornblende microdiorite dikes that cut a post-Kotsina fault north of the Kotsina River (locality *H*, fig. 2) and are themselves unconformably overlain by beds of Hauterivian age. These relations are shown on figure 3. Assuming that a significant period of time was required to fault the Kotsina Conglomerate, intrude the dikes, erode the rocks on the west side of the fault to the level of the dikes, and then to submerge the area to receive the Hauterivian sediments, then a Jurassic age for the Kotsina Conglomerate seems likely.

Support for, and considerable refinement of, the stratigraphic age of the Kotsina Conglomerate is

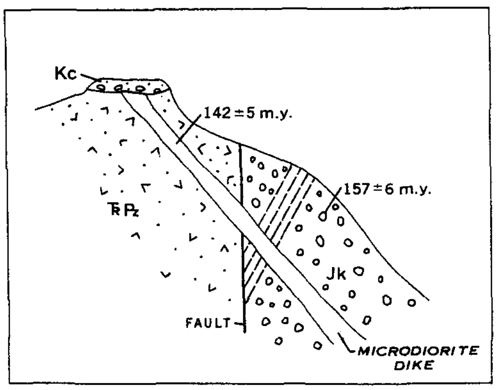


FIGURE 3.—Schematic geologic section showing the field relations critical to dating the Kotsina Conglomerate. Ages were determined by the potassium-argon method. The section is located on the north side of the Kotsina River (loc. *H*, fig. 2). Geologic units are identified by letter symbol on figure 2.

provided by potassium-argon ages determined for hornblende in one of the microdiorite dikes (sample 2, table 1) which cut the conglomerate and in a biotite grandiorite clast (sample 1, table 1) from the conglomerate in the same outcrop. The age determined for hornblende from the dike is 142±5 million years, and that for biotite from the clast is 157±6 m.y. These determinations indicate a minimum age of Late Jurassic and suggest a Middle or Late Jurassic age for the Kotsina Conglomerate. The biotite age is in good agreement with potassium-argon ages of biotite and hornblende from plutons in the Talkeetna Mountains (Grantz and others, 1963) and the Aleutian Range (Detterman and others, 1965). The stratigraphic evidence in these two areas suggests that emplacement of these plutons occurred in latest Early to earliest Middle Jurassic time. The biotite age for the Kotsina Conglomerate clast suggests that the plutonism which was widespread in the area of the Matanuska geosyncline also occurred locally in the area of the Kotsina Conglomerate.

An age of 141±5 m.y. (sample 3, table 1) was determined for hornblende from a granodiorite pluton near Kuskulana Pass (loc. *E*, fig. 2). This pluton intrudes latest Triassic rocks and is overlain unconformably by Lower Cretaceous (Hauterivian) rocks. Its indicated age is significantly less than the ages that have been measured for granitic rocks in the Talkeetna Mountains and Aleutian Range, which were noted above.

The ages of the hornblende from the pluton at Kuskulana Pass and from the dike which intrudes the Kotsina Conglomerate north of the Kotsina River (samples 2 and 3, table 1) are, however, in excellent agreement, and are considered to represent a Late Jurassic plutonic episode.

#### Sandstone and lutite

Other rocks in the southwestern Wrangell Mountains that may be Jurassic crop out in the bluffs along the Chetaslina and Cheshnina Rivers (fig. 2). These rocks consist mostly of sandstone and lutite and dip 25° to 30° SW. The outcrops along the Cheshnina River lie downdip from nearby outcrops of the Kotsina Conglomerate which they resemble more closely in degree of induration and deformation than they do the Cretaceous rocks of the area.

The most abundant rock type is greenish-gray, thick-bedded feldspathic and lithic graywacke that is locally crossbedded and calcareous. It ranges from fine-grained to very coarse grained and pebbly sandstone with angular to subrounded grains that are generally poorly sorted. The sandstone contains many interbeds and units of pebble-and-cobble conglomerate, dark-gray siltstone, and mudstone intraclasts. Most of the conglomerate clasts are volcanic rock fragments, but some are granitic, and others are sandstone or limestone. Plant scraps and a few marine fossils have been found in the sandstone and its siltstone interbeds.

Downstream from the main sandstone outcrops on the Cheshnina River, and possibly overlying them, are green to gray lutites with thin sandstone interbeds at some places. These interbeds of sandstone are dark greenish gray and fine grained, and they locally have graded bedding and sole markings. Apparently the stratigraphically highest rocks are shaly and silty claystone and siltstone that contain brownish gray-weathering limestone interbeds and concretions.

The sandstone beds are estimated to be more than 1,000 feet, and are possibly more than 2,000 feet thick. Neither the top nor the base of the section is exposed. The lutites are at least several hundred feet thick, but in places they are in tight southeast-striking isoclinal and chevron folds, and their thickness could not be determined during the present reconnaissance.

These rocks were mapped as nonmarine and of Tertiary age by others (Moffit, 1939, pl. 2; Mendenhall, 1905, pl. 4). During the present studies, however, a belemnite and *Inoceramus* scraps were found in sandstone on the Chetaslina River, and several small pelecypods and small ammonites in outcrops on the Cheshnina River. Ralph W. Imlay, of the U.S. Geological Survey, states (written commun., 1963) that although the ammonites cannot be positively identified, they resemble immature forms of *Kepplerites*, or some related genus, of Callovian age, and that an early Late Jurasic age seems probable.

## CRETACEOUS ROCKS

#### Clastic rocks of Early Cretaceous (Neocomian) age

Marine sedimentary rocks of Neocomian age form many small mountaintop outcrops between Long Glacier and Kuskulana Valley and constitute a larger area of continuous exposures near Kuskulana Pass (fig. 2). Correlative beds previously referred to as the tuffaceous units of Middle Jurassic age crop out south of the Chitina River in the northern Chugach Mountains. Moffit and Mertie (1923) described the Neocomian beds in some detail but were puzzled by their stratigraphic complexity and age and their relation to the Kotsina Conglomerate. Indeed, mollusks from these beds have been assigned by various paleontologists to the Middle Jurassic, Late Jurassic, Early Cretaceous, and Late Cretaceous (Moffit and Mertie, p. 44–48; Moffit, 1938, p. 66–70; Imlay and Reeside, 1954, p. 231).

The Neocomian beds are much less deformed than the latest Triassic and older rocks upon which they rest with angular unconformity, and near Kuskulana Pass (loc. *E*, fig. 2) they overlie granodiorite for which a potassium-argon age of 141±5 m.y. was obtained on hornblende (sample 3, table 1). They are overlain, apparently unconformably, by beds of Albian age.

The Neocomian rocks are clastic marine deposits, but they are characterized by an almost white calcarenite facies which is composed of finely comminuted prisms of *Inoceramus* shell. Sandstone beds with lower proportions of biogenic calcite grains are brownish gray, greenish gray, or olive gray. North of the Chitina River these rocks are mostly fossiliferous, cross-bedded, calcareous sandstone and conglomerate. The thickest sections are from 600 to almost 1,000 feet thick. The sandstone and conglomerate intertongue greatly, and the stratigraphic sections differ widely from place to place (see Neocomian columnar sections, fig. 2). As with the nearby Kotsina Conglomerate, the conglomerate and sandstone clasts are chiefly greenstone, limestone, and argillite, and were derived from the subjacent formations. These rocks are nearshore, high-energy, shallow-water deposits.

North of the Chitina River, from 0 to 200 feet of rounded cobble-and-boulder conglomerate with a calcareous matrix, and in places containing many mollusks, occurs at the base of the Neocomian sequence. In the section north of the Kotsina River (loc. *B*, fig. 2) beds overlying the basal conglomerate are at least 600 feet thick. The lower 200–300 feet consist of calcareous sandstone that is fine to coarse grained and conglomeratic. The sandstone is fossiliferous, cross-bedded, and contains beds and lenses of calcarenite and of coquinoid sandstone. It in turn is overlain by a similar thickness of medium-dark and greenish-gray sandy siltstone with many, commonly large, mollusks. The upper part of the section consists of fossiliferous coarse sandstone, conglomerate, and calcarenite. At one place, about 60 feet of sandstone and conglomerate at the base of the upper coarse clastic rocks is overlain by about 50 feet of thick-bedded, very light gray (almost white), generally fine grained calcarenite with large *Inoceramus* shell fragments and some lenses of terrigenous pebbles and sand. The calcarenite section is overlain by a small thickness of incompletely exposed calcareous sandstone. Within one large outcrop the calcarenite interfingers with calcareous conglomerate, and it is evidently supplanted by fossiliferous calcareous sandstone and conglomerate within a quarter of a mile to the west. At one place the basal 5 feet of the calcarenite interfingers with pebble conglomerate and lenses out within a horizontal distance of 6 to 8 feet. The calcarenite may represent a nearshore bar or bank of wave-comminuted shell fragments which abutted an area in which terrigenous detritus was being deposited in shallow water from a nearby stream mouth.

Correlative Neocomian beds in the northern Chugach Mountains south of the Chitina River and near its mouth (locs. *C* and *D*, fig. 2), are grossly similar in lithology to those north of the river. They are thicker, however, and include a thick unit of dark siltstone. Moffit (1914, p. 25-27) reported that these Neocomian rocks (loc. *C*, fig. 2) south of the Chitina River (which he considered Middle Jurassic) consisted of (1) a lower unit at least 500–600 feet thick composed of massive conglomerate with rounded pebbles and cobbles of argillite, diorite, greenstone, and quartz, set in a tuffaceous matrix, and (2) an upper unit several hundred feet thick of fossiliferous tuffaceous beds "... composed of dark fine-grained sandstone-like rock, slightly calcareous, and showing numerous small flakes of mica on the cleavage surface." Moffit mapped the upper unit as tuffaceous slate (1914, pl. 2), and tuffaceous shale (1938, pl. 2). He stated that the conglomerate appeared to rest unconformably upon Carboniferous(?) schist, but that the contact was poorly exposed and at many places appeared to be a fault. Moffit's description of these rocks suggests that they are calcareous conglomerate and siltstone lithologically like the Neocomian clastic rocks north of the Chitina River. However, three fossil collections from the upper unit were studied by T. W. Stanton (Moffit, 1914, p. 26), who referred them to the Middle Jurassic. These collections were reexamined during the present study and found to consist of fragmentary mollusks that could be either Jurassic or Cretaceous and that would not be out of place in the Hauterivian faunule collected from similar rocks about a mile to the east during the present study.

During the present reconnaissance the Neocomian rocks south of the Chitina River were examined only in a small stream at the east end of their outcrop area (loc. *D*, fig. 2) and their relationship to the rocks described by Moffit was not determined. Along this stream more than 800 feet of dark, fairly hard, fossiliferous glauconitic siltstone is exposed. It contains layers of thick *Inoceramus* shells and thin interbeds of calcareous sandstone and coarse siltstone crowded with *Inoceramus* prisms. This thick, fossiliferous siltstone probably was deposited somewhat farther from shore than the thinner and coarser equivalent rocks north of the river. The siltstone section is overlain by a few hundred feet of calcareous conglomerate and sandstone that contains abundant *Inoceramus* prisms and has some interbeds of siltstone and of graywacke conglomerate and sandstone. As in the outcrops to the north, the conglomerate is dominated by clasts of altered volcanic rocks, limestone, black chert, and argillite, and contains some granitoid rocks and rarely quartz.

The abundant molluscan faunule in the lower and middle parts of the section (loc. *B*, fig. 2) north of the Kotsina River contains species of *Inoceramus*, *Pinna*, *Simbirskites*, and a belemnite which are probably of Hauterivian (late Neocomian) age. The same faunule was obtained from the dark siltstone south of the Chitina River (loc. *D*, fig. 2). The calcarenite near the top of the section north of the Kotsina River contains *Inoceramus ovatoides* of Anderson, which is of late Hauterivian to Barremian (late Neocomian) age. The genus *Simbirskites* in Europe is of middle to late Hauterivian age.

The Hauterivian beds of the southwestern Wrangell Mountains are correlative with the Nelchina Limestone and overlying dark sandstone in the Nelchina area of the Talkeetna Mountains, which Bergquist (1961) found to contain Hauterivian Foraminifera. The Nelchina Limestone is an almost white calcarenite characterized by *Inoceramus* shell fragments and prisms. The Nelchina Limestone overlies *Buchia*-bearing sandstone and conglomerate of Valanginian (early Neocomian) age which is absent in the Wrangell Mountains.

#### Siltstone, shale, and sandstone of Early Cretaceous (Albian) age

Albian-age rocks crop out in a broad syncline at Kuskulana Pass (loc. *G*, fig. 2), where they rest with apparent unconformity on the Neocomian beds just described, and in a small area on the southeast flank of Mount Drum (loc. *A*, fig. 2). The beds near Mount Drum have a moderate dip to the west and rest upon biotite granodiorite. Biotite from this pluton yielded a potassium-argon age of $126\pm4$ m.y. (sample 4, table 1), suggesting intrusion during Neocomian (Early Cretaceous) time. The fact that the unconformity at the base of the Hauterivian (upper Neocomian) beds in the Kotsina-Kuskulana Rivers area represents a greater structural discordance and a longer hiatus than the unconformity at the base of the overlying Albian beds suggests that the pluton was intruded before deposition of the upper Neocomian beds of the Kotsina-Kuskulana Rivers area, and that it was unroofed by a combination of pre-Hauterivian and pre-Albian erosion.

The Albian rocks at Kuskulana Pass are similar to strata cropping out near Fourth of July Pass in the upper Chitina Valley that have been designated the Kennicott Formation. However, usage of the name Kennicott has been so varied that use of the term should be suspended until detailed mapping is accomplished in the type area. At Kuskulana Pass the Albian rocks (loc. *G*, fig. 2) are about 1,500 feet thick and are dominantly siltstone. Some sandstone may occur at the base of the section, but the lowest beds are poorly exposed at the place visited. The bulk of the section is siltstone, silty claystone, and shale that are slightly greenish gray and medium dark gray and weather to medium gray, brownish gray, or greenish gray. The siltstone contains limestone concretions and lentils and a few volcanic ash layers. An interval 150 feet thick in the lower part of the sequence contains abundant shells of the pelecypod *Aucellina* in limestone concretions and coquinoid beds. Another interval at least 200 feet thick in the middle of the sequence contains 5 to 10 percent of thin to thick interbeds of coarse siltstone, sandstone, and minor conglomerate. These interbeds resemble turbidites, being commonly graded, and many show sole markings, wavy bedding, small-scale crossbedding, and channeled bases. The uppermost exposed beds in this section are siltstone and silty claystone with limestone concretions, but the top of the section is not preserved. Fossils were not obtained from the highest beds, and thus their age is unknown. A few observations along the northeast side of the syncline at Kuskulana Pass suggest that sandstone and conglomerate interbeds in the middle of the sequence may increase in number and thickness to the north.

The Albian strata near Mount Drum are lithologically quite different from those at Kuskulana Pass, for they are characterized by very carbonaceous silt and clay shales and contain beds of granite wash. They are also slightly younger. The exposed section (loc. *A*, fig. 2) exceeds 650 feet in thickness. Its basal part is 350 feet thick and consists mostly of gray, soft siltstone and silt shale resting on granodiorite. It contains large limestone concretions with marine fossils, wood fragments, and glauconite grains. Medium to very thick interbeds of arkose, mostly coarse and pebbly, and of granite wash are distinctive features of this unit. The thickest of these interbeds are composed of angular and subangular granitic blocks mixed with intraclasts of sandstone and limestone, yet they are separated from the underlying granodiorite by tens of feet of shallow marine siltstone. These relationships suggest that the basal Albian sea floor had appreciable relief, and that the coarse detritus was dumped in and buried without significant reworking, even though the beds are apparently of shallow marine origin.

Dark, very carbonaceous, and commonly fissile brownish-gray-weathering shale and siltstone, 175 feet thick, overlie the basal unit. These rocks have yielded some animal trails but no other fossils. The carbonaceous character of these beds, the presence of trails, and the absence of mollusks within them suggest that they are of brackish-water or lagoonal origin. The uppermost 140 feet of the exposed section is dark, chunky, and platy weathering siltstone that contains large limestone concretions, some of which contain marine fossils. The top of the unit is unexposed, but the section is overlain by Cenozoic volcanic rocks.

The basal beds near Mount Drum contain *Brewericeras hulenense* and other ammonites of the *Brewericeras hulenense* local faunizone of late early Albian age. The upper beds contain *Puzosia alaskana* Imlay of probably the same age. *Aucellina*, which is restricted to the lower lower Albian zone of *Moffitites robustus*, is apparently absent from the Mount Drum section, which is therefore slightly younger than the *Aucellina*-bearing Albian beds at Kuskulana Pass. The Mount Drum section is also lithologically different from that at Kuskulana Pass; it more closely resembles the Albian beds of the northern part of the Nelchina area, which consist of coaly beds overlain by very fossiliferous shallow marine shale. The lithologic differences between the Albian rocks of Kuskulana Pass and Mount Drum suggest that the former should be named according to the formal stratigraphic nomenclature applied to the upper Chitina Valley, and the latter according to the nomenclature of the Nelchina area and Copper River lowland.

The upper Mesozoic rocks of the southwestern Wrangell Mountains record at least three episodes of deep erosion followed by sedimentation. These episodes are recorded at (1) the base of the Kotsina Conglomerate, (2) the base of the Neocomian beds, (3) the base of the Albian beds. These rocks also record evidence of plutonism of latest Early or earliest Middle Jurassic age, of Late Jurassic age, and of Early Cretaceous age within or near the Matanuska geosyncline. These rocks have some overall lithologic similarities to rocks of similar age in nearby areas, but their stratigraphic sequence is nevertheless quite different from that found in the nearby areas. These relations illustrate that these rocks were deposited in a tectonically active trough that typically produced rocks that are lithologically similar over wide areas, but which are arranged in highly distinctive and variable local sequences. Long-range extrapolation of local stratigraphic details in these rocks is, therefore, a risky enterprise.

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# OCCURRENCE OF PYROPHYLLITE IN THE KEKIKTUK CONGLOMERATE, BROOKS RANGE, NORTHEASTERN ALASKA

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*Abstract.*—Pyrophyllite occurs in the matrix of the Upper (?) Devonian or Mississippian Kekiktuk Conglomerate. Pyrophyllite may have formed from the alteration of kaolinite or other high-alumina clay minerals during low-grade metamorphism.

The Kekiktuk Conglomerate is a thin, locally absent Upper (?) Devonian or Mississippian conglomerate in the northeastern Brooks Range (Brosgé and others, 1962). It underlies the Upper Mississippian Kayak (?) Shale and overlies with angular unconformity the Neruokpuk Formation of Devonian or older age. Although the pyrophyllite described here is from the vicinity of Lake Peters (fig. 1), a sample of lithologically similar Kekiktuk Conglomerate (made available by W. P. Brosgé) from the Kongakut River also contains considerable pyrophyllite. This sample locality is 80 miles east of Lake Peters and indicates that the occurrence of pyrophyllite in the Kekiktuk Conglomerate is not restricted to the Lake Peters area. Other pre-Kayak (?) quartzite on the south side of the eastern Brooks Range is also known to locally contain pyrophyllite (W. P. Brosgé, oral communication, 1965). From the description the pyrophyllite in the Sioux Quartzite (Berg, 1938) appears to be somewhat similar to the pyrophyllite in the Kekiktuk Conglomerate. In the Yakkabag Mountains, in the Soviet Union, Shumara (1965) has described pyrophyllite related to secondary quartzites which are found among volcanogenic rocks. However, the pyrophyllitization is restricted to the volcanogenic rocks; the associated sedimentary rocks underwent silicification.

## STRATIGRAPHY

### Neruokpuk Formation

In the Lake Peters area (fig. 1) the Neruokpuk Formation consists of interbedded quartz wacke, quartz semischist and phyllite with lesser amounts of chert and conglomerate. Detrital feldspar and rock fragments in the quartz semischist and quartz wacke are each less than 10 percent of the total rock. Mineral assemblages of the wackes, semischists and phyllites commonly include quartz, albite ($<An_5$), muscovite, and chlorite. Chloritoid is locally present and epidote is rare. The rocks of the Neruokpuk Formation have been regionally metamorphosed to the quartz-albite-muscovite-chlorite subfacies of the greenschist facies (Turner and Verhoogen, 1960, p. 534–537). The rocks in general possess a well-developed metamorphic fabric, but no evidence of a polymetamorphic history was seen. Uplift occurred subsequent to regional metamorphism and folding, and more than 10,000 feet of Neruokpuk rocks was eroded off prior to Kekiktuk deposition. The contact, where exposed, between the Neruokpuk Formation and the Kekiktuk Conglomerate is sharply defined. Any regolith that may have developed on the erosion surface of the Neruokpuk Formation would have subsequently been removed during the depositional regime of the Kekiktuk Conglomerate.

### Kekiktuk Conglomerate

The Kekiktuk Conglomerate is composed of 0 to 350 feet of resistant generally massive irregularly bedded units of quartzite and varying amounts of medium to thick, lenticular beds of pebble and cobble conglomerate. Thin lenses of siltstone are locally present. The siltstone is light to dark gray and weathers light gray and pale yellowish brown to reddish brown. The quartzite consists of medium-grained to granule size angular to subrounded strained and unstrained quartz grains with a few dark-gray chert grains in a matrix of quartz, pyrophyllite, and minor sericite (sericite as used in this paper refers to a very fine-grained 2M muscovite). Secondary quartz overgrowths are locally abundant, but welding and interpenetration of detrital quartz grains are more com-

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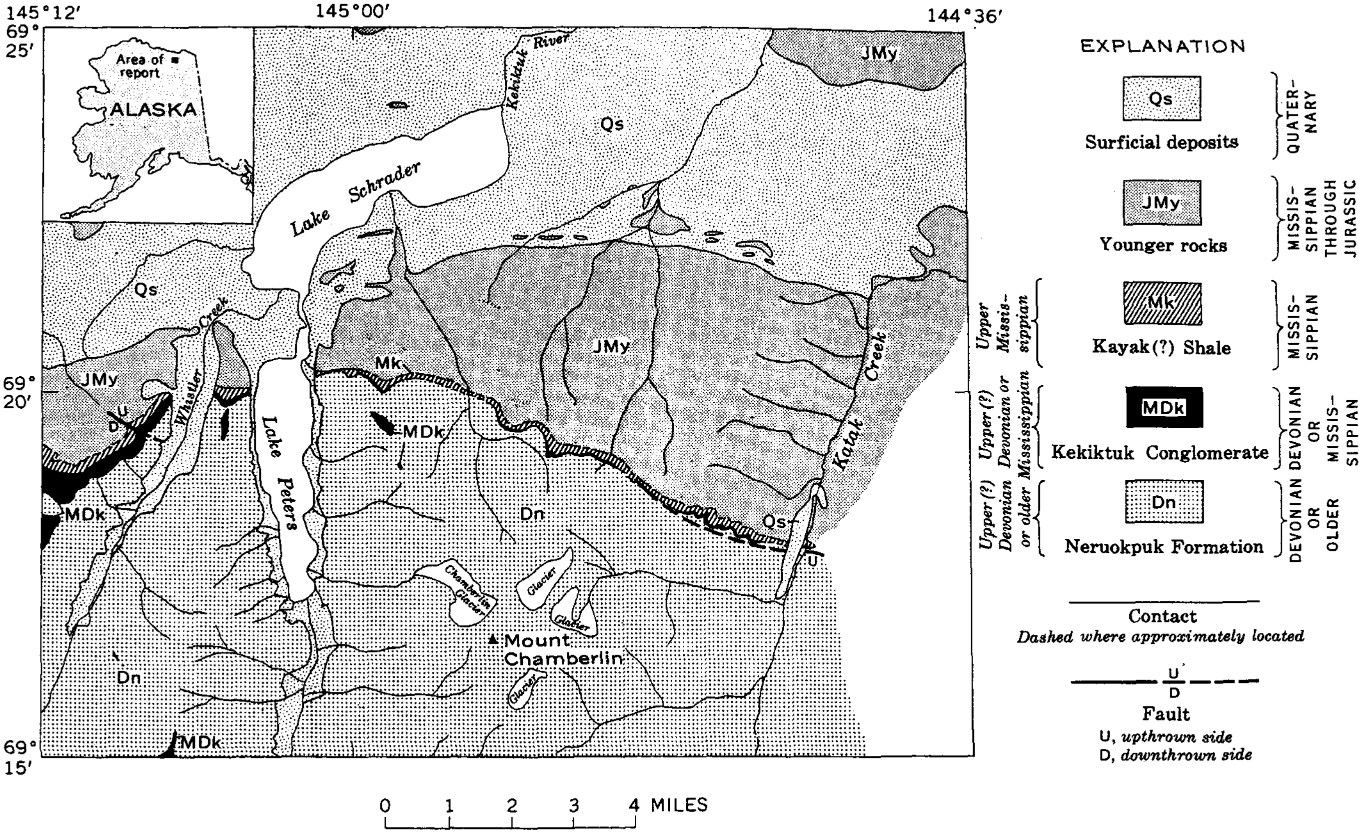


FIGURE 1.—Generalized geologic map of the Lake Peters area, northeastern Alaska, showing distribution of the Kekiktuk Conglomerate.

mon. Interstitial quartz is present as microcrystalline anhedral grains and as clear secondary quartz adjacent to welded grains. At a few places twinned detrital plagioclase grains occur in the specimens collected. Heavy minerals include tourmaline, ilmenite, magnetite, cassiterite, and rutile. Pebbles and cobbles in the conglomerate consist of quartz, metachert, and a few clasts of phyllite and quartzite. The conglomerate commonly occurs at the base of the formation, although discontinuous beds and lenses are found at higher levels. The general appearance of the formation suggests rapid deposition of gravel as sheets or channels, probably as an ancient fluvial deposit of a piedmont or flood-plain type.

### Kayak(?) Shale and younger rocks

The Kayak(?) Shale consists of argillite and siltstone with limestone occurring near the top of the formation. Mississippian through Jurassic limestone, sandstone, and shale overlie the Kayak(?) Shale (fig. 1); these rocks do not contain pyrophyllite. They are metamorphosed however, and slaty cleavage is locally developed. Igneous rocks are not present in the Lake Peters area.

## OCCURRENCE OF PYROPHYLLITE

Pyrophyllite occurs as a matrix mineral in the quartzite and conglomerate of the Kekiktuk Conglomerate. Of 22 samples examined (collected throughout the map area) 20 contain pyrophyllite. It also occurs in minor amounts in the underlying Neruokpuk Formation and the overlying Kayak(?) Shale. It is restricted, however, to within a few feet of both contacts with the Kekiktuk Conglomerate. Pyrophyllite in quartzite is easily overlooked in the field. A thin yellowish-gray film of pyrophyllite fills the interstices between quartz grains, and the characteristic soapy feel of pyrophyllite is absent even in specimens containing as much as 30 percent (by weight) pyrophyllite. Because pyrophyllite is difficult to distinguish from sericite in thin section, positive identification was made by X-ray diffraction.

The pyrophyllite occurs as fine compact feltlike aggregates of small clear crystals that range from 0.02 to 0.1 mm in length. It occurs in slightly broader platy crystals than does the less common sericite. The larger crystals of pyrophyllite occasionally form poorly developed radiating rosettes. Its birefringence is high, and 2V is greater than 45°.

Pyrophyllite fills interstices between quartz grains and replaces the original matrix, quartz overgrowths, and detrital quartz grains (fig. 2). In places pyrophyllitization is so complete that it is difficult to identify the original texture of the replaced matrix. Small irregular patches of unreplaced quartz are locally present within the pyrophyllite; in extreme cases of pyrophyllitization there is an absence of original detrital quartz outlines, and only isolated, embayed fragments of the original quartz grains remain (fig. 3). Strained quartz grains show a greater tendency for replacement than do unstrained grains. As much as 40 percent (by weight) of pyrophyllite may be present in some samples, but in general it makes up less than 20 percent of the rock. X-ray diffraction patterns show 2M muscovite as a minor constituent in 11 of the samples.

## STABILITY FIELD OF PYROPHYLLITE

The upper stability limit of kaolinite and of kaolinite in equilibrium with quartz has been the subject of considerable experimental work (Roy and Osborn, 1954; Carr and Fyfe, 1960). Unfortunately the results of these studies, although sometimes quoted in literature, cannot be taken as the thermodynamic stability limit of kaolinite. They are based either upon gel crystallizations or upon short-term unreversed thermal decomposition runs. The true limit of stability is therefore lower, and perhaps considerably lower, than these findings would indicate.

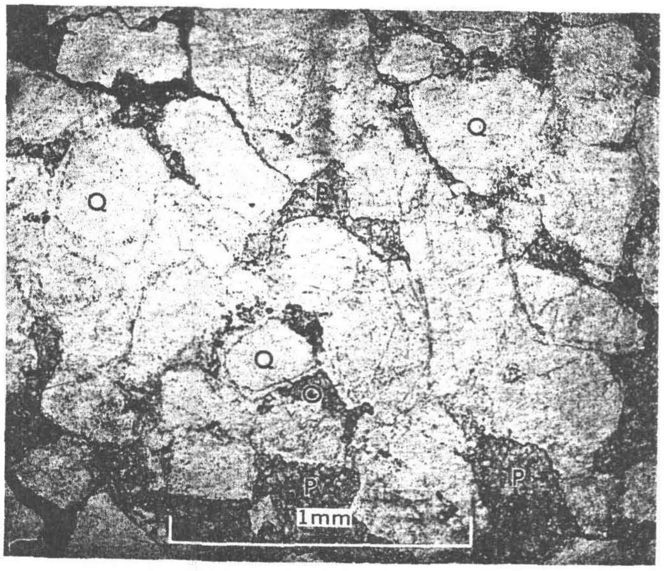


FIGURE 2.—Photomicrograph showing quartz overgrowths (O), detrital quartz grains (Q) and pyrophyllite (P). Most of the contacts among adjacent grains are between authigenic overgrowths, but the number of detrital grain contacts is high. Plane light.

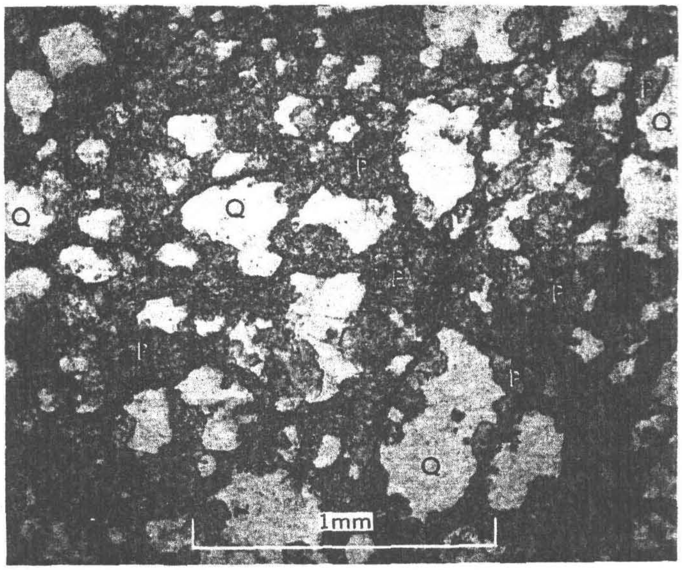


FIGURE 3.—Photomicrograph showing extreme case of pyrophyllitization in quartzite of the Kekiktuk Conglomerate. In most of the photomicrograph there is a lack of detrital grain outlines, and only embayed fragments of the original grains remain. (Q) quartz, (P) pyrophyllite. Plane light.

In a pure water environment Hemley and Jones (1965) observed the reaction kaolinite + quartz to pyrophyllite in the region of 380°C, 1,000 bars $P_{H_2O}$ (partial pressure of water), in runs of moderate (several weeks) duration. The reaction is:

$$Al_2Si_2O_5(OH)_4+2SiO_2 \rightarrow Al_2Si_4O_{10}(OH)_2+H_2O.$$

In earlier work (Hemley, 1959), decomposition temperatures 20° to 30°C lower than this were realized in a dilute electrolyte environment (water activity still very close to that of pure water at the given pressure and temperature). More important, however, is the result of a run of long duration (1 year) in which pyrophyllite was produced from kaolinite plus quartz (Hemley, unpublished data) at 300°C and 1,000 bars $P_{H_2O}$. A stability limit no higher than about 300°C at 1,000 bars is thus indicated. This observation has been further corroborated by extensive solubility work on kaolinite and pyrophyllite by Hemley in the same experimental program, the results of which are being compiled for publication. Finally, it is apparent that at lower water pressures and higher silica activities the upper stability limit of kaolinite would be further depressed. These controls have important implications to the present geological discussion.

A possible origin for the pyrophyllite that is consistent with the quartz-pyrophyllite-sericite assemblage is summarized below. Extensive weathering of the Neruokpuk Formation, and the depositional regime associated with the profound unconformity at the base of the Kekiktuk Conglomerate, produced a quartzite containing minor clay minerals, particularly kaolinite-type clays, but relatively free of feldspar or other mineral contaminants. During folding and low-grade metamorphism, pyrophyllite was formed by reaction of kaolinite with associated quartz.[1]

Lenses of siltstone within the quartzite, which probably had a high content of clay minerals originally, contain considerably more pyrophyllite than does the quartzite. This suggests that clay minerals were the source of the alumina required to form pyrophyllite. The temperatures and pressures at which pyrophyllite formed are uncertain. Temperatures may have been as much as 300°C, but most likely were much lower. The preserved thickness of rocks overlying the Kekiktuk Conglomerate is about 5,000 feet. However, there may have been an additional 5,000 feet or more of younger sedimentary rocks (post-Jurassic) that have been eroded off. In any event a lithostatic pressure of from 400 to 900 bars is indicated. Water pressure, on the other hand, may have been much lower than this lithostatic pressure. Also, the kaolinite to pyrophyllite transition should be favored not only by low $P_{H_2O}$, but also by a large differential between total pressure (including some possible tectonic overpressure) and in itself favors the phase of higher density and lower the $P_{H_2O}$, in the rock inasmuch as confining pressure hydration and entropy (Fyfe and others, 1958).

Because quartz is present as a major constituent, aqueous silica concentration was probably at least equivalent to quartz saturation in the pore fluid phase, but supersaturation may also have developed at least locally during metamorphism. Lithostatic stress on contacts between quartz grains would increase their solubility, causing solution and redeposition of silica. This increase in aqueous silica concentration would favor the reaction between silica and clay minerals. Strained quartz grains would tend to show preferential replacement by pyrophyllite inasmuch as grains in such a state have a decreased thermodynamic stability. That the fabric of the rock points to the operation of these processes is evidenced by petrographic features described in a previous paragraph.

Thus, there is no apparent inconsistency between known experimental relations in the alumina-silica-water system and the occurrence of pyrophyllite in this geologic setting. The most important requisite for pyrophyllite formation under the pressure and temperature conditions of low-grade metamorphism is a bulk composition relatively pure in alumina-silica. Where such conditions are not met, chlorite, muscovite, and other typical greenschist minerals are produced. For example, the overlying Kayak argillite contains predominantly 2M muscovite and chlorite. Although pyrophyllite is confined essentially to the Kekiktuk Conglomerate, it does occur in the overlying Kayak (?) Shale and underlying Neruokpuk Formation. It is confined in these rocks, however, to within a few feet of the contacts. This limited distribution apparently reflects the influence of the conglomerate as the source of the silica during metamorphism, which locally migrated into the overlying and underlying rocks and reacted with pockets of aluminous clay minerals to form pyrophyllite. Minor potassium is also present in Kekiktuk quartzite, reflected by the occurrence of minor sericite.

Low-grade metamorphism (greenschist facies) can yield pyrophyllite from the appropriate bulk composition with or without the presence of water as a phase. On the basis of the similarity of pyrophyllite to sericite in thin section, the apparent scarcity of pyrophyllite in low-grade metamorphic rocks may be more apparent than real. More X-ray work in the future will resolve this question. Furthermore, sediments, soils and weathering products rich in Al and Si and low in associated cations (kaolinitic-type materials) are not rare geologically. Therefore if pyrophyllite is indeed a rare mineral in quartzose metamorphic sections, it would imply that metasomatic processes (such as K introduction to form sericite) apparently accompany low-grade metamorphic processes in most instances.

[1] Montmorillonite, of course, may also have been present and involved in the metamorphic event, but montmorillonite reactions and stability relations are not quite as well understood as those of kaolinite, and the fact that montmorillonite contains minor base cations would require some leaching as well as simple reaction with silica in the metamorphic process.

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